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REVIEWS

Die kristallinen Schiefer. By DR. U. GRUBENMANN. Vol. I, 1904; Vol. II, 1907. Zurich.

The recent work of Dr. Grubenmann, *Die kristallinen Schiefer*, Vol. I, aims, as its author states in the preface, to explain the characteristics of the crystalline schists, and their occurrence in the crust of the earth, according to chemical-physical laws. Although restricted to one phase of metamorphism, the motive of the work has much in common with *The Principles of Metamorphism* by Dr. C. R. Van Hise. Its general conclusions are, however, quite different.

Dr. Grubenmann briefly follows the historical evolution of conceptions relating to the origin of the crystalline schists, and discusses the original materials of the schists, and their specific characteristics. The cited criteria of sedimentary origin are: stratification, fossil record, micro- and megafragmental relicts, conglomerates, ripple-marks, delta formations, gradation phases, chemical composition, and abrupt changes in mineralogical composition within very narrow limits. The criteria given for igneous origin are: chemical composition, gradation phases, and the preservation of original forms of occurrence such as dikes, sills, stocks, and laccoliths.

The processes enumerated by which the original materials are metamorphosed into crystalline schists are mechanical reconstruction, recrystallization, and remineralization. The factors which, in conjunction with time, enter into these processes are solvents, heat, pressure, and the specific characteristics of the original materials.

Dr. Grubenmann makes a threefold division of the crust of the earth into an upper, middle, and lower zone, based on the predominance of one or more of the factors of metamorphism. The belt of weathering (Van Hise) is excluded from the upper zone.

The conditions named for the upper zone are moderate temperature and low hydrostatic pressure, positive heat-toning,¹ and powerful stress. The predominant pressure effect is mechanical. Heat liberation and decrease of volume result from the chemical reactions. The abundance of water favors the development of hydroxide minerals, such as sericite,

¹ The "heat-toning" of a reaction is positive when the sum of the resulting heats of formation exceeds the sum of the heats of formation of the vanished molecule.

chlorite, talc, zoisite, and epidote. These minerals, with quartz and calcite, form the characteristic rocks of this zone—namely, sericite-phyllite, sericite-quartzite, lime-phyllite, albite-phyllite, talc, and chlorite-schists, etc.

The conditions named for the middle zone are higher temperature and intense stress, stronger hydrostatic pressure, and positive and negative heat-toning. The predominant effect of pressure is recrystallization and remineralization with decrease in volume. The minerals assigned to this zone as characteristic are biotite, zoisite, epidote, hornblende, staurolite, garnet, disthene, titanite, magnetite, ilmenite, muscovite, microcline, albite, and oligoclase. The typical rocks of this zone constitute the great mass of the crystalline schists: mica-schists, amphibolites, garnet, and staurolite-schists.

The specified conditions of the lowest zone are enormous hydrostatic pressure and high temperature, very feeble stress, and negative heat-toning. The reactions are inferred to take place with volume increase, since the minerals of this zone nearly all belong to Löwinson-Lessing's "plus" group. ("The molecular volume of the minerals of the plus group exceeds the molecular volumes of the oxides which compose them.") Dr. Grubenmann argues from this that the reactions are probably controlled by temperature and not by pressure. The minerals which are described as peculiar to this zone are cordierite, magnetite, sillimanite, ilmenite, orthoclase, plagioclase, biotite, augite, olivine, and garnet. The gneisses constitute the predominant rocks.

A number of mineral and rock alterations are cited as peculiar to each zone. Olivine of the lowest zone becomes hornblende or garnet in the middle, and serpentine in the upper zone. Granulation of grain, chloritization, and sericitization occur in the upper zone. An aluminous sediment composed of kaolinite, quartz, mica, feldspar, iron oxide, and lime becomes a phyllite in the upper zone, a mica schist in the middle, and a gneiss containing feldspar, sillimanite, and other anhydrous minerals, in the lower zone.

Dr. Grubenmann's threefold division is not intended to apply to all the lithosphere with regard to metamorphic processes, since it is concerned with the development of the crystalline schists only. In a broad way, the three zones collectively correspond to Van Hise's zone of anamorphism and rock-flowage. Anyone who has made a field study of the crystalline schists appreciates the difficulty of classifying them according to the metamorphic processes to which they owe their origin, since no direct observational evidence can be obtained to form the basis of such a classification. Although Dr. Grubenmann refers to the occurrence of schist zones in

certain truncated anticlines, and infers their order of superposition, the reader finds, as a whole, that the field evidence on which his threefold classification is based does not stand out very clearly. In fact, the reader gathers the impression that the threefold classification is based rather on inferences drawn from certain mineral associations than on decisive field observation of the existence of three zones.

Dr. Grubenmann infers that the reactions in the two uppermost zones occur with volume-decrease, since the characteristic minerals of this zone mostly belong to Löwinson-Lessing's "minus" group; i. e., their molecular volume is less than the molecular volume of the oxides which compose them. Most of his readers will probably not agree to this method, but will consider the actual volume-changes involved in the mineral alterations. Various investigators have shown that the alterations described as peculiar to these zones—chlorization, serpentinization, and sericitization—generally involve increase of volume.

In the lower zone also he considers the molecular volume relations between the minerals and their constituent oxides as indicative of the volume-changes caused by the reactions. He argues that the occurrence of "plus" minerals, like orthoclase, plagioclase, and sillimanite, indicates volume-increase. However, calculations of the actual mineral volume-change involved in their formations from other minerals show a decrease in volume.

In the second volume Dr. Grubenmann distinguishes twelve groups on the basis of chemical composition, which are delimited by empirically derived chemical values. The groups take their nomenclature from the rock formations which are peculiar to them. They are: (I) orthoclase gneisses, (II) alumino-silicate gneisses, (III) plagioclase gneisses, (IV) eklogite and amphibolite, (V) magnesian-silicate gneisses, (VI) jadeite rocks, (VII) chloromeianite rocks, (VIII) quartzitic rocks, (IX) lime-silicate rocks, (X) marbles, (XI) iron-oxide rocks, and (XII) alumino-oxide rocks. Each group is subdivided into orders, which are based on the physical characteristics assumed by a group in the upper, middle, and lower zone respectively. A group-name takes the prefix "kata" when it designates a rock of the first order or of the lowest zone. The prefix "meso" is applied to rocks of the middle zone or the second order; and the rocks of the third order or the upper zone take the prefix "epi." Frequently the orders are subdivided into families, based on mineral composition.

The first step in identifying the position of a crystalline schist in Dr. Grubenmann's system is to ascertain its chemical composition. The per-

centage weights of TiO_2 and P_2O_5 are converted into their equivalent weights of SiO_2 and added to the latter. In the same way Fe_2O_3 and MnO are added to FeO , and BaO and SrO are united with CaO . H_2O is neglected. The seven oxides resulting from this elimination are recalculated on a basis of 100, and then converted into molecular percentages. The molecular percentages are then distributed as follows:

S = molecules of SiO_2 .

A = sum of molecules of $\text{K}_2\text{O} + \text{Na}_2\text{O}$ united with Al_2O_3 in the ratio of 1:1.

C = CaO united to Al_2O_3 in the ratio of 1:1.

F = sum of FeO and MgO . If Al_2O_3 is deficient, the remaining CaO is added to F.

M = CaO added to F.

T = excess of Al_2O_3 after satisfying CaO and the alkalies in the ratio of 1:1.

$$K = \frac{\text{SiO}}{6A + 2C + F}.$$

These seven so-called group values, S, A, C, F, M, T, and K, are the "empirically derived chemical values" which delimit the groups. Besides these values, Dr. Grubenmann has adapted¹ Osann's² projection values, a, c, f, to the chemical classification of the crystalline schists.

The determination of the texture, structure, and mineral content of the schist completes the examination necessary for the complete identification of a schist according to Dr. Grubenmann's system.

Dr. Grubenmann does not claim to have produced a perfect system of classification. The zonal conceptions, he admits, are not entirely free from well-founded objections. A separation into two zones, he believes, would in many cases be more in accord with the facts of occurrence.

Die kristallinen Schiefer may be regarded as an excellent summary of known facts relating to the crystalline schists. It also contains new material. With present incomplete knowledge it is not possible to say whether the proposed classification is warranted and supported by the facts in the field. Perhaps its greatest service to the science consists in proposing a new theory which points out the necessity of a far more detailed investigation of the crystalline schists than has been made thus far.

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¹ See *Tschermak's mineralogische und petrographische Mittheilungen*, Vol. XIX, p. 351.

² $a = \frac{20A}{A+C+F}$; $c = \frac{20C}{A+C+F}$; $f = \frac{20F}{A+C+F}$.